CG9-13

HYDRAULIC SERVOVALVE RELIABILITY IMPROVEMENT STUDY FOR NASA

Progress Report #5 Nov. 1 - Dec. 1, 1964
Contract No. NAS8-11630
NASA Procurement & Contracts Office
George C. Marshall Space Flight Center

Approved by: ____________________
Engineering Manager

Approved by: W H Pollock
Program Manager

Prepared by: ____________________
Project Engineer

Sept 27111

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1.0 INTRODUCTION

This is the fifth monthly progress report of a Hydraulic Servovalve Reliability Improvement Study conducted by Cadillac Gage Company for NASA under Contract NAS8-11630.

The action during this report period included preliminary developmental testing of the 12 ma jet pipe servovalve. Brazing techniques have also been solved which resulted in an acceptable jet pipe suspension assembly capable of withstanding designed pressures.

Availability of all necessary hardware permitted experimentation to optimize the torque motor force outputs resulting in pole piece and armature design changes.

Initial valve tests revealed nozzle oscillations in the audible range. Several remedies are being attempted to increase the first stage damping ratio.

Additional parts are being fabricated to include design changes dictated by the results of the initial tests.

2.0 CONCLUSIONS

Initial testing of the servovalve led to two conclusions, one of which is really a confirmation of the findings revealed during the Phase I portion of the Servovalve Reliability Improvement study. This conclusion is rather obvious but is being reiterated here for emphasis. It pertains to the quality of the nozzle jet stream. Unless the jet stream is concentrated and constant over the range of pressures up to the operating pressure of the valve, excessive null shift and instability results.

The quality of the jet stream depends primarily on the smoothness of the fluid contract surfaces, sharpness of the orifice corners at the discharge point and the concentricity and the entrance angle to the orifice. Visual inspection of the nozzle is not adequate to predict the jet, actual tests must be performed prior to its installation in the valve.

The second conclusion pertains to the efficiency of torque motor air gaps. Experimental tests led to the conclusion that flat faced air gaps are more efficient in torque motor design than ones encircling a round armature. Experiments were performed in which the air gaps and air gap areas were maintained constant and the flat face air gap torque motor showed a 21% greater centering force output.

It is theorized that flat faces permit the magnetic lines of flux, when passing from the armature to the poles, to remain parallel to each other and to bridge the gap at right angles. This constitutes the shortest path of resistance. In a round armature and pole face design, the lines of flux are disturbed from a parallel path seeking the shortest path of resistance. Consequently, it appears that excessive concentration of flux occurs at the outer edges of the poles resulting in greater stray losses.

Paragraph 5.1.1 discusses these phenomena in greater detail.

3.0 HISTORY

The first month of the program was spent in design and fabrication of a new jet pipe and armature suspension device and experimental torque motor, and a preliminary design of a new 12 ma jet pipe servovalve.

The second report period covered two months of work. The new servovalve design required more time to solve design details than was first anticipated. The second report was further delayed to include the results of the experimental torque motor evaluation.

Hardware manufacturing follow up and design of test procedures were the activities during the fourth report period.

This, the fifth report period includes evaluation of the brazed jet pipe and armature assembly, torque motor testing and preliminary development of the complete servovalve. The activity concentrated largely on noise and instability of the valve and the isolation of factors affecting the quality of the nozzle jet stream.

4.0 PHASE II PROGRAM OUTLINE

The following is an outline and detailed breakdown of the Phase II Program. Phase II of the servovalve reliability improvement study consists of three distinct parts being conducted in sequence according to the availability of manpower. It is believed that the schedule is a realistic representation of the program and includes the slippages of milestones occuring to date and those anticipated. Figure I is a milestone chart graphically illustrating the effort planned. No slippages occured during the current reporting period.

4.1 Part I - 12 MA Servovalve (Complete by 1-29-65)

This portion of the program deals with the design and development of a flow control valve packaged to an optimum size and weight envelope. Upon the successful completion of the development, this valve will be simultaneously life tested in a fluid contaminated to a minimum of three (3) times the NASA recommended levels for comparison with the 50 ma valve developed under Phase I of this study.

4.1.1 Design, detail and release for fabrication (Completed 8-28-64).

4.1.2 Fabricate (Completed 11-13-64).

4.1.3 Evaluation and development testing (12-28-64).

4.1.3.1 Reworks and adjustments.

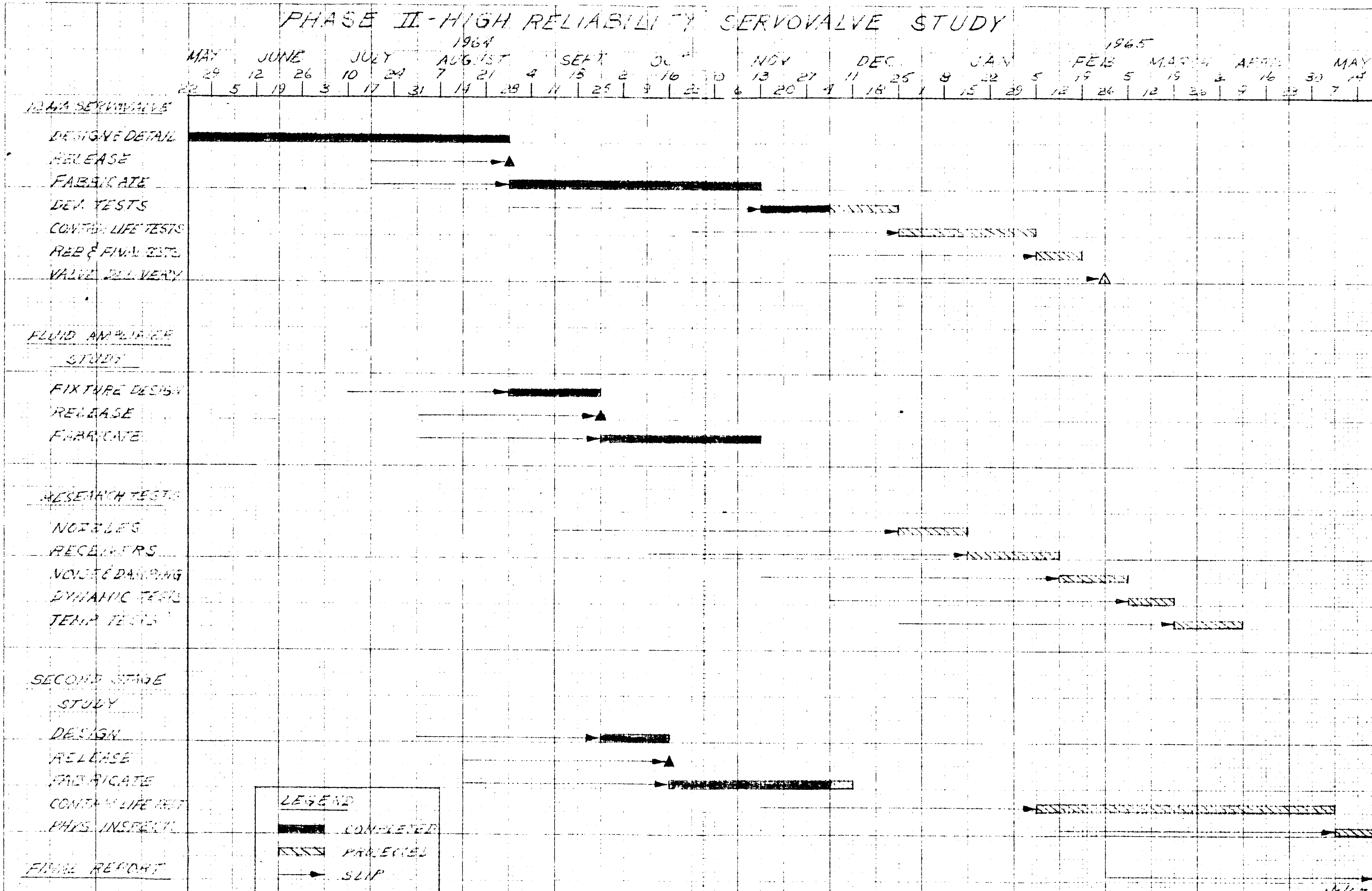

PHASE II - HIGH RELIABILITY SERVOVALVE STUDY
1964
1965
MAY
JUNE
JULY
AUGUST
SEPT
OCT
NOV
DEC
JAN
FEB
MARCH
APRIL
MAY
DESIGN & DETAIL
RELEASE
FABRICATE
DEV. TESTS
REB & FINAL TESTS
VALVE DELIVERY
FLUID AMPLIFIER STUDY
FIXTURE DESIGN
RELEASE
FABRICATE
NOZZLES
RECEIVERS
SECOND STAGE STUDY
DESIGN
RELEASE
FINAL REPORT
LEGEND
COMPLETED
PROJECTED
SLIP
6/1/65

FIG. 1

4.1.4 Contamination life testing (Complete by 2-5-64).

4.1.4.1 Control and maintenance of contamination levels at a minimum of three (3) times NASA Specification.

4.1.4.2 Daily performance tests, complete disassembly and visual inspection, and detailed testing every 50 hours.

4.1.4.3 100 hours running time at various frequencies.

3.1.4.4 Data reduction and report.

4.1.5 Servovalve rebuilding and final tests.

4.1.6 Valve delivered to NASA (2-26-65)

4.2 Part II - Jet Pipe Fluid Amplifier Study (Complete by 4-16-65)

This portion of the program is designed to increase the general knowledge of jet pipe amplifiers. The test program is oriented to obtain non-dimensionalized raw data which can be used in a computer study.

4.2.1 Test fixture design, detail and release for fabrication (Completed 9-25-64).

4.2.2 Fabrication (Completed 11-13-64).

4.2.3 Test Program (Complete by 4-16-65)

4.2.3.1 Nozzles - Evaluation of parameters contributing to the condition of the jet stream. L/d ratio, entrance angles, surface conditions, pressures, temperatures, straight length of pipe up stream of nozzle. Relationship of stream quality to momentum forces developed.
Results of these tests could be used in predicting pressure recovery efficiencies of given size receivers.

4.2.3.2 Round Receivers Evaluation - Pressure, flow recoveries, characteristic load flow curves, noise levels.

4.2.3.3 Square Receiver Evaluation - Pressure, flow recoveries, characteristic load flow curves, noise levels.

4.2.3.4 Noise Reduction - Raised receivers, inverted nozzle chamfers, web thickness, receiver exit hole geometry.

4.2.3.5 Damping Methods - Back pressure, artificial damping devices.

4.2.3.6 Dynamic Response - Relationship of characteristics load flow curves to dynamic response and stability. Transient response.

4.2.3.7 High and Low Temperature Tests - Cold temperature transient response, static and dynamic characteristic at extreme low temperatures, noise levels, performance characteristics at high temperatures, noise levels. Relationship of fluid viscosity to noise.

4.3 Part III - Second Stage Study (Complete by 5-21-65)

This portion of the program is designed to evaluate three (3) different spool profiles under contaminated life test conditions. Each of three different designs will be tested to determine the rate of performance degradation as related to a particular design. In addition, an inspection and manufacturing evaluation will be performed to determine the fidelity of the parts obtained to the actual paper design.

4.3.1 Design, detail and release for fabrication a test fixture and slide valves (Completed 10-15-64). Three spool profiles will be designed.

1. Multigroove
2. Cadillac Gage Standard
3. Narrow Landed

4.3.2 Fabrication (Complete by 12-11-64) - Four of each of three designs will be fabricated with sufficient overrun to assure 12 acceptable assemblies. Final criteria for acceptance will be spool displacement force levels.

4.3.3 Life Tests (Complete by 5-7-65) - Three sets, 100 hours each set with disassembly and inspection at conclusion. Tests conducted in fluid at a minimum of three (3) times NASA contamination levels.

4.3.4 Physical Inspection (Complete by 5-21-65)

4.4 Final Report (6-4-65)

5.0 ACTION FOR PERIOD NOVEMBER 1 TO DECEMBER 1, 1964

The following paragraphs describe the work performed during the above referenced period.

5.1 12 MA Servovalve Development

5.1.1 Torque Motor Tests

During the development of a successful brazing technique, three armature and jet pipe suspension assemblies failed to pass the pressure tests and were eventually scrapped. One of these however, was good enough to conduct dry torque motor tests.

The spring rate of the pivot tubes was tested at 209 in-lb/rad which was much too stiff for this torque motor. Inspection of the pivot tubes revealed the walls to be on the high dimensional tolerance design. The spring pivots were then lapped to obtain a spring rate of 150 in-lb/rad.

Optimum adjustment of the air gaps gave the centering torque output of .19 in-lb at 12 ma input current. See Figure 2. The torque output represents .27 lb force at the air gaps since the lever arm from the pivots to the center of the air gaps is .70 inches. This output however, was less than the desirable .4 to .45 lb.

NASA JET PIPE VALVE

TORQUE VS CURRENT

10-30-64

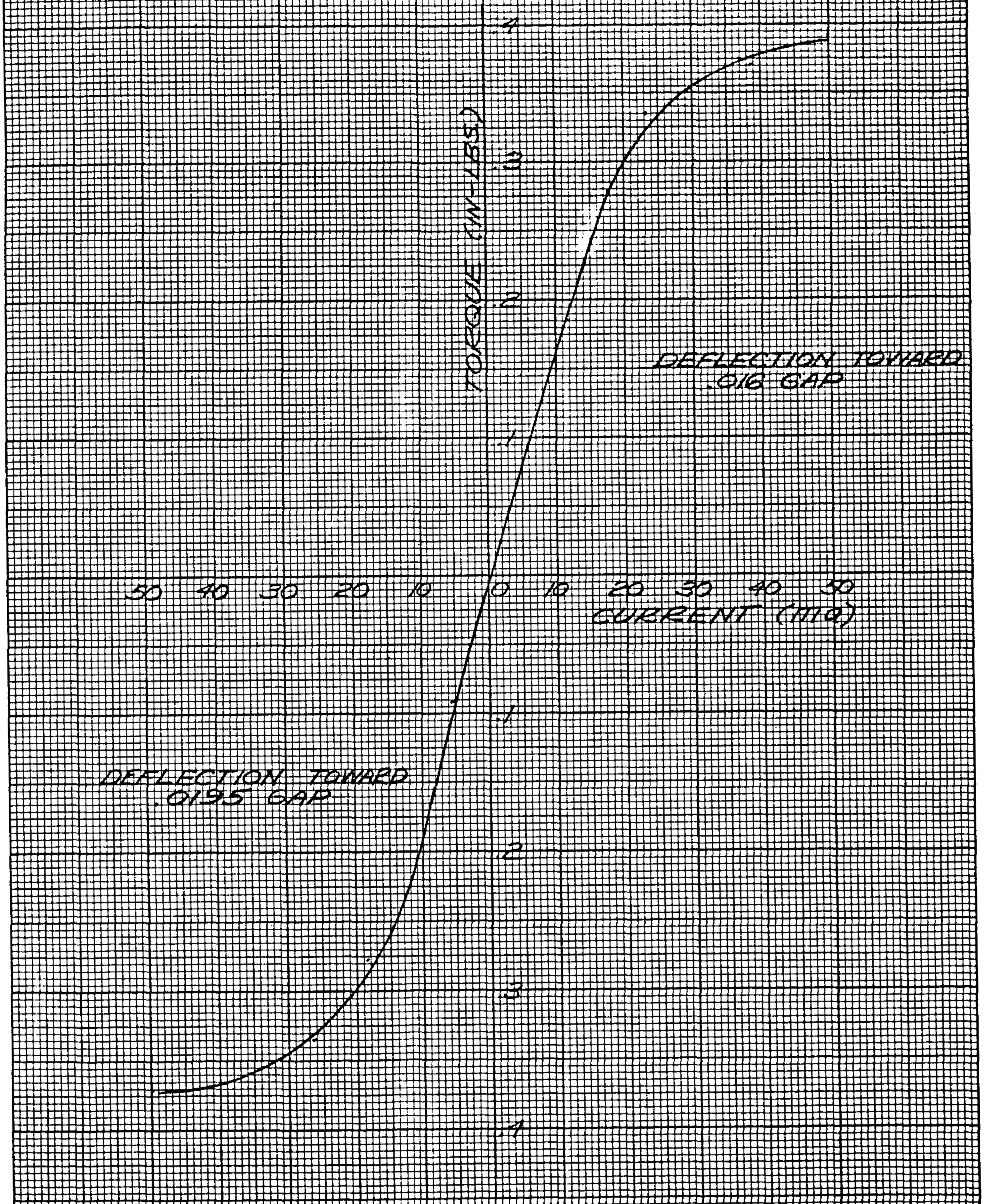
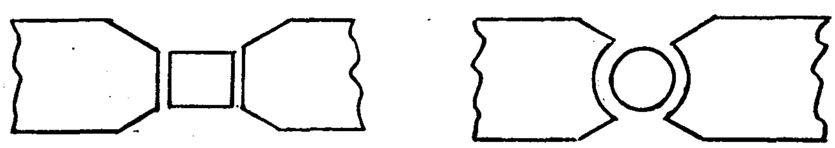


FIG. 2

Several experiments were then conducted. The first of these involved a substitution of curved pole faces with flat ones and an adapter for the armature to match the flat surfaces. The air gap area was not changed. Figure 3 shows the curve obtained with the flat faces. An immediate force increase of 21% was achieved. This was accomplished with a better balance between the air gaps.

It is believed that the increase in torque output with flat pole faces is a result of a better distribution of the lines of flux. The sketch below shows the two air gap configurations.



It may be readily seen that in the case of flat pole faces, the air gaps are constant and at right angles to the magnetic flux path. In the wrap-around pole face configuration, the greater portion of the air gap is not normal to the flux path. Consequently, it is believed that the flux, in the process of bridging the gap, is distorted in its path from the armature to the pole.

Additionally, when the armature is displaced, the air gap becomes

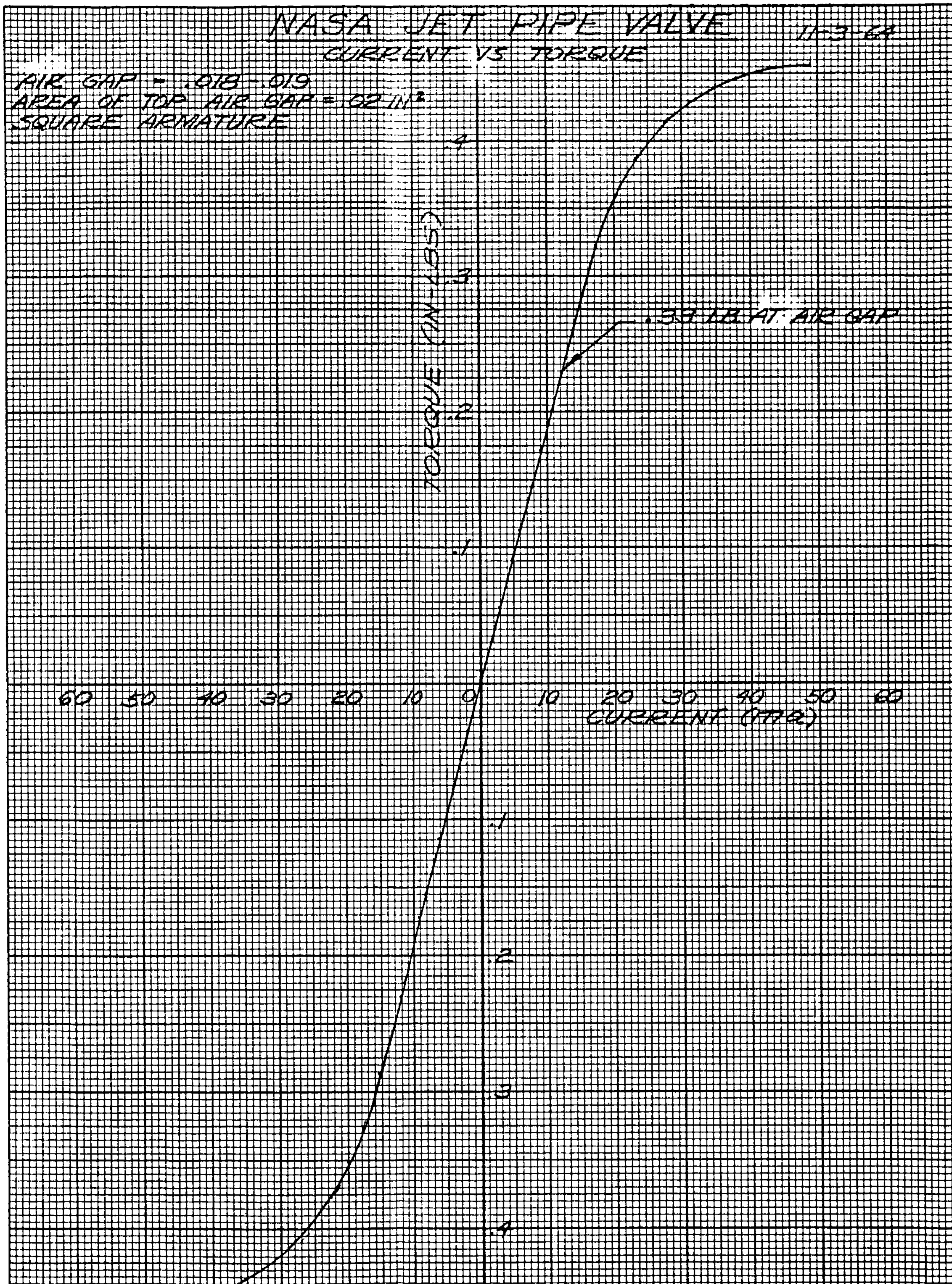
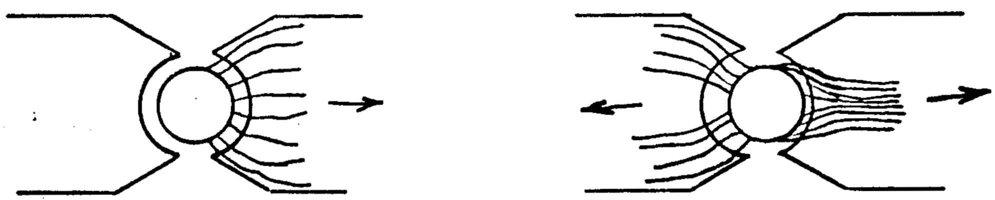

NASA JET PIPE VALVE
11-3-64
CURRENT VS TORQUE
AIR GAP = .018 - .019
AREA OF TOP AIR GAP = .02 IN²
SQUARE ARMATURE
.33 LB. AT AIR GAP
TORQUE (IN-LBS)
CURRENT (MA)
.4
.3
.2
.1
60
50
40
30
20
10
0
10
20
30
40
50
60
.1
.2
.3
.4

FIG. 3

uneven as shown in the sketch below.



The center portion of the air gap becomes much smaller while the outer portions remain essentially the same. Thus, the flux tends to concentrate in the center resulting in saturation spots which tend to reduce the efficiency of the torque motor.

Several torque output tests were conducted to determine the effects of various sizes of the top and bottom air gaps. These are shown on Figure 4. The tests pointed to the fact that the initial setting of the air gaps gave optimum torque outputs. In order to increase the output and open up the top air gaps therefore, it was necessary to increase the air gap area.

The top air gap was then increased from .02 in^2 to .035 in^2. This resulted in the same torque motor output with .025 in. air gaps as previously obtained with .018 - .019 in. gaps. By adjusting the gaps until the torque motor was just stable, the torque output was increased to .31 in-lb with the same signal level. Figure 5 shows the two curves obtained.

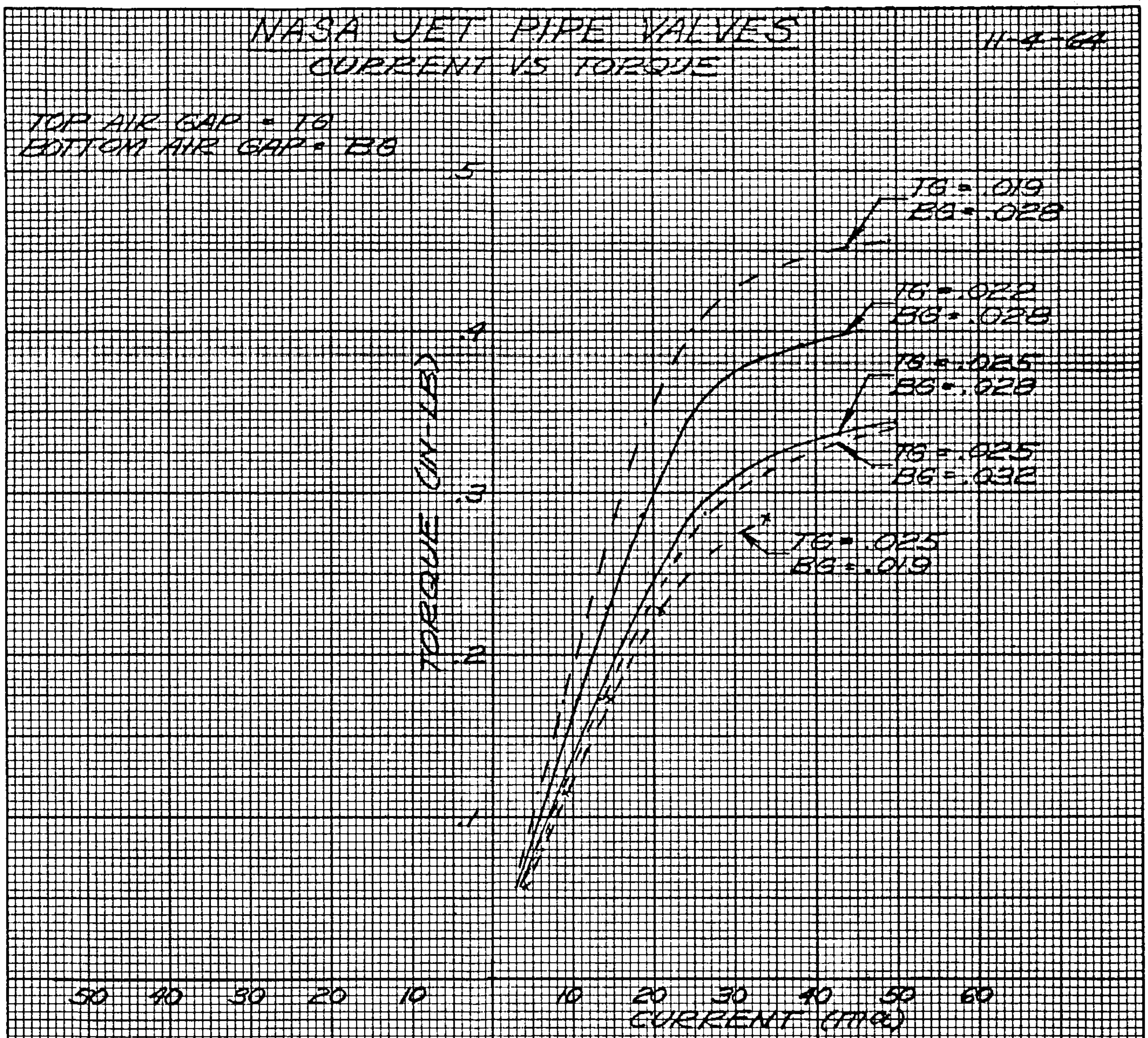

NASA JET PIPE VALVES
CURRENT VS TORQUE
11-4-64
TOP AIR GAP = TG
BOTTOM AIR GAP = BG
TORQUE (IN-LB)
5
4
3
2
1
TG = .019
BG = .028
TG = .022
BG = .028
TG = .025
BG = .028
TG = .025
BG = .032
TG = .025
BG = .019
50 40 30 20 10 10 20 30 40 50 60
CURRENT (MA)

FIG. 4

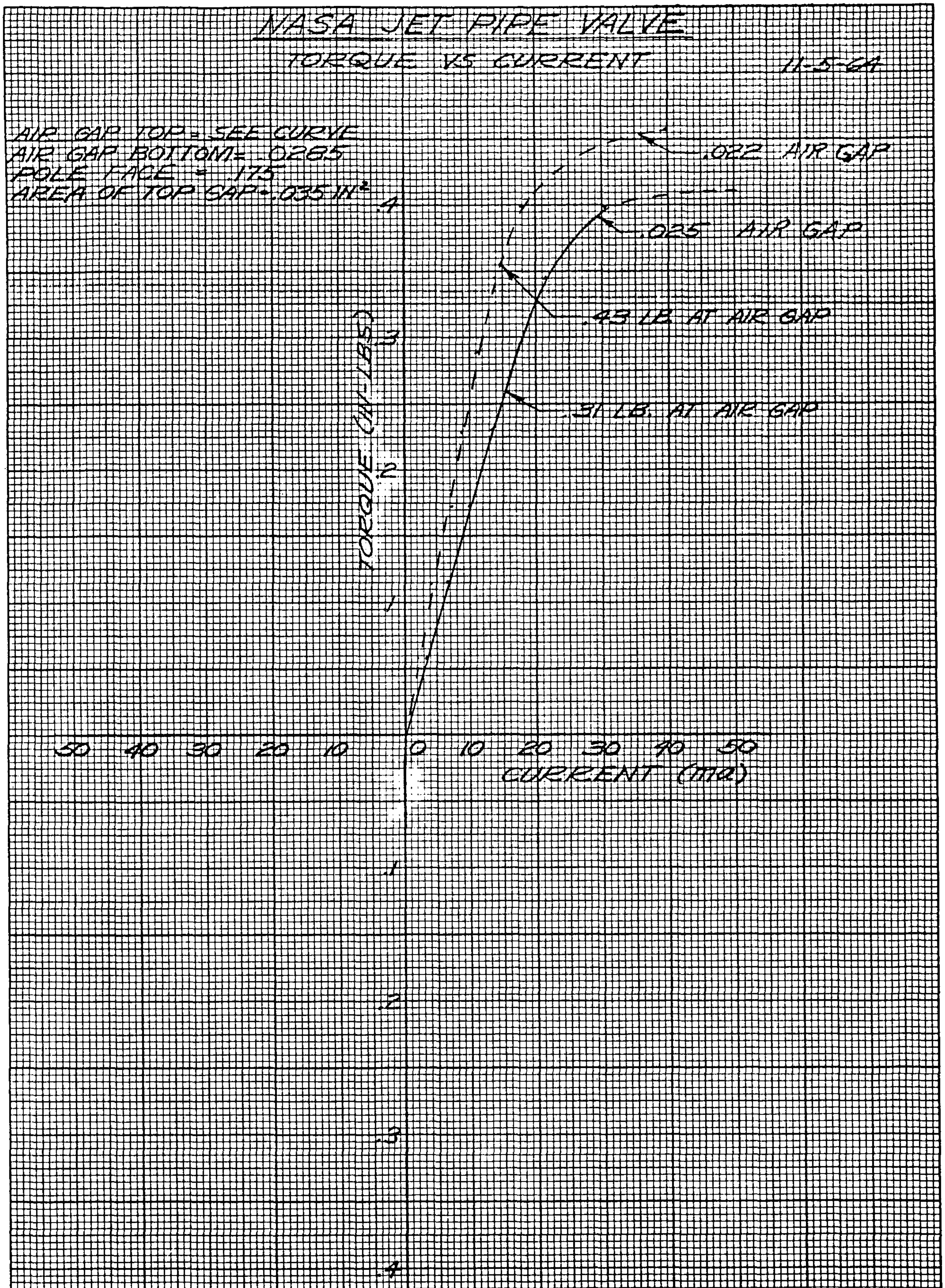

NASA JET PIPE VALVE
TORQUE VS CURRENT
11-5-64
AIR GAP TOP = SEE CURVE
AIR GAP BOTTOM = .0285
POLE FACE = .175
AREA OF TOP GAP = .035 IN²
.022 AIR GAP
.025 AIR GAP
.43 LB. AT AIR GAP
.31 LB. AT AIR GAP
TORQUE (IN-LBS)
.4
.3
.2
.1
.1
.2
.3
.4
50
40
30
20
10
0
10
20
30
40
50
CURRENT (ma)

FIG. 5

5.1.2 Nozzle Jet Stream - Development

The receipt of an acceptable pressure tight jet pipe and armature suspension assembly permitted completion of the valve build up. Prior to assembly into the valve, tests were conducted to observe the quality of the jet stream through out the pressure range of 0-3000 psi. The first nozzle exhibited a jet stream that shifted and dispersed very noticeably with increasing pressures. However, this nozzle was installed into the valve to observe its effects on the operation of the servo. The valve exhibited excessive null shift with varying supply pressure plus instability and full rated signal shift with return pressure.

The valve was then disassembled and a new nozzle was installed. The new nozzle exhibited a steady concentrated jet stream up to 3000 psi. At rated pressure, the jet remained solid for about two inches from the nozzle before it began to disperse. The null shift tests were rerun as before and the results are shown on Figure 6 for comparison. Although the null positions are different, the change itself is much smaller with a good nozzle.

A visual inspection of the bad nozzle was made with the aid of a microscope. It was found to have drill marks in the orifice, ragged

NASA JET PIPE VALVE

NULL SHIFT WITH RETURN AND SUPPLY 12-3-64

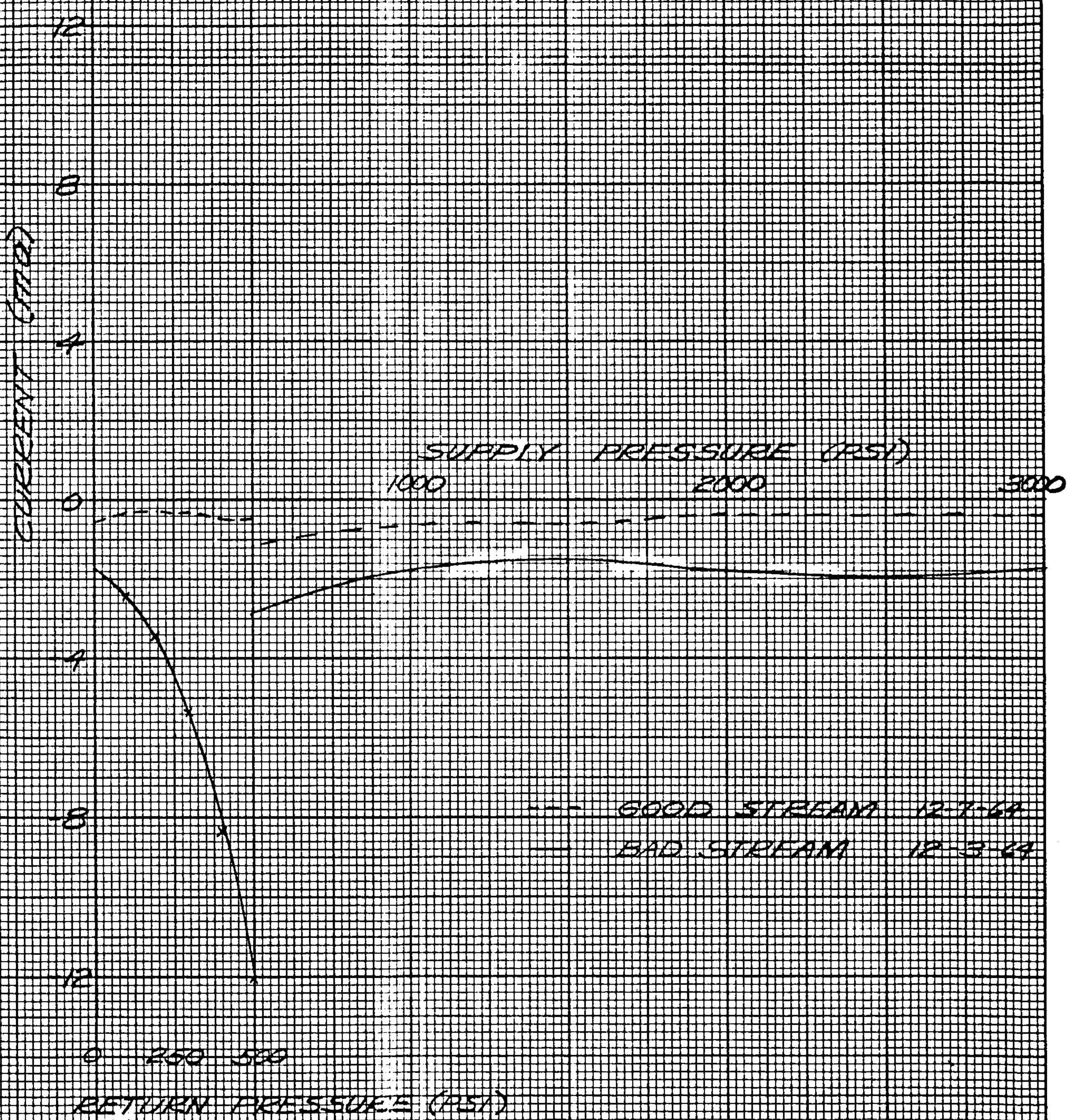


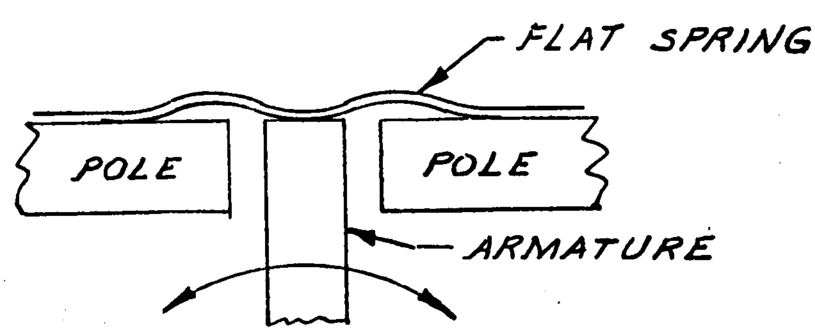
FIG. 6

corners at the discharge surface and inlet surfaces. An acceptable jet stream was obtained when these surfaces were polished and the corners were made sharp.

5.1.3 Instability and Noise

Initial testing of the servovalve revealed oscillations when the valve is operating near null. These oscillations originate at the nozzle and are within the audible range. With the aid of an oscilloscope, these oscillations were found to be in the 850 cps range.

Several experiments were attempted to reduce or eliminate the oscillations. These included a shield around the nozzle and a return orifice to pressurize the nozzle chamber up to 200 psi without success. Then a friction damper was installed. This consisted of a flat beryllium copper spring across the top of the torque motor. The spring makes a three point contact, two of which are held securely to the pole pieces and the middle one bears on the top of the armature as shown in the sketch below.



This damper appeared to be very successful. The oscillations were completely eliminated.

To determine the effect of the damper on the overall hysteresis of the torque motor, a first step pressure gain curve was conducted with and without the spring in place. The two curves showed no noticeable increase in hysteresis. The pressure gain curve was purposely chosen over the overall valve flow plot to insure full armature swing for this test since it is well known that during normal operation of a mechanical feedback type valve, this armature remains essentially at null.

Future ideas on damping methods may include a shield around the armature which would be filled with viscous fluid to provide pure viscous damping. Additional weights to the armature-nozzle tube assembly are being avoided since the entire structure is now effectively mass balanced.

5.2 Nozzle Testing

Progress Report #3 included the Jet Pipe Fluid Amplifier Study Test Plan. This plan described the procedure for conducting nozzle tests. These tests are designed to map the pressure distribution curve of the jet stream issuing from the nozzle with the aid of strain gages.

The jet stream analyzer fixture was completed including the installation of the strain gages. The check out showed good correlation between designed and actual deflections of the reed. The output of the strain gages however, required high amplification to obtain an output sufficiently high to actuate an X-Y recorder. Consequently the output is slightly non linear. This non-linearity is not expected to create major problems since relative values rather than absolute values are being sought. Figure 7 shows the relationship between the reed deflection and strain gage outputs.

5.3 Status of the Second Stage Study

All of the hardware has now been fabricated except for final fitting of the spools and sleeves. It is expected that these operations will be completed on schedule.

JET STREAM ANALYZER

11-30-64

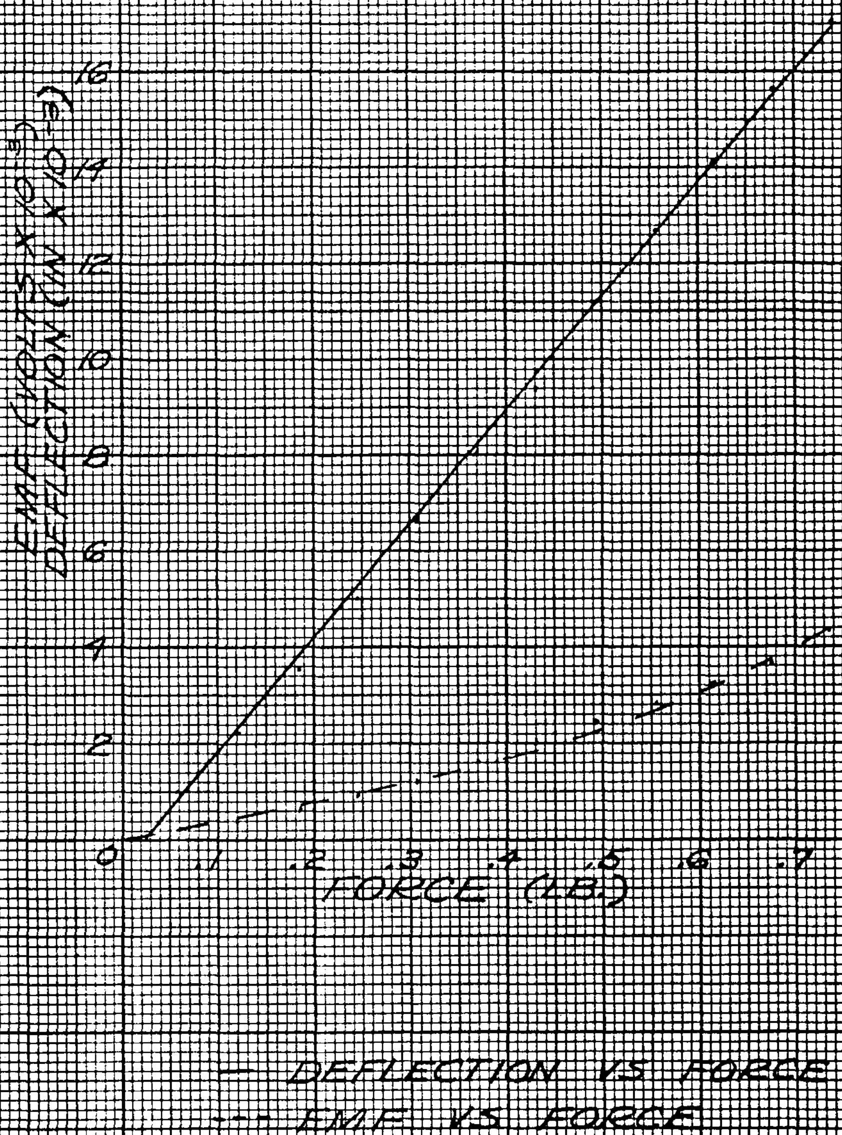


FIG. 7

6.0 Future Action Planned

Further development testing of the servovalve will proceed as soon as new jet pipe suspension assemblies are brazed. The existing one, although pressure tight, is too rigid for this torque motor design. New armatures and pole pieces are being made to incorporate the flat air gap design.

Additional jet pipe suspension assemblies will also permit the start of the Jet Pipe Amplifier Study portion of this project.